Fermi National Accelerator Laboratory

FERMILAB-Conf-98/141-E
E898

BooNE, the LSND Effect, and Opportunities for Short Baseline Neutrino Facilities

Ray Stefanski
For the E898 Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

May 1998

Published Proceedings of the *Workshop on Physics at the JHF (JHF98)*,
KEK, Tsukuba-shii, Ibaraki, Japan, March 4-7, 1998

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

Fermilab-Conf-98/141-E
May 15, 1998

BooNE, the LSND Effect, and Opportunities for Short Baseline Neutrino Facilities [a]

Presented by Ray Stefanski for the BooNE Collaboration.
Fermi National Accelerator Laboratory,
P.O. Box 500,
Batavia, Il 60510

1 Introduction

The Booster neutrino experiment [1] consists of a 12 meter diameter tank, filled with nearly pure mineral oil, and outfitted with 1250 phototubes (see Fig. 1). To be built at Fermilab, located 500 meters from a horn/ targeting system (see Fig. 2) it will function as a short baseline neutrino detector to explore the region of parameter space that contains the LSND [2] effect. An experiment that will measure the effect with a significance (signal to background) greater than ten, it will determine the existence of the effect, and with a phase two upgrade involving the construction of a second detector, measure the properties of the effect.

The Fermilab Booster is an 8 GeV rapid cycling synchrotron that operates as the source for the Main Injector. It can deliver as many as (5×10^{12}) protons per 2μsec pulse at a rate of 15 Hz. Only about 1/2 of the 15 Hz rate will be used by the future Fermilab program, leaving 7 to 10 Hz available for other uses. The BooNE experiment will take advantage of this available source of protons.

In this paper, we give a review of the capabilities of the BooNE experiment, and compare to the potential reach of other sites, including the JHF. A brief description of the potential of a muon storage ring is also discussed.

[a] Presented at the Workshop on Physics at the JHF (JHF98) KEK, Tsukuba-shii, Japan, March 4-7, 1998.

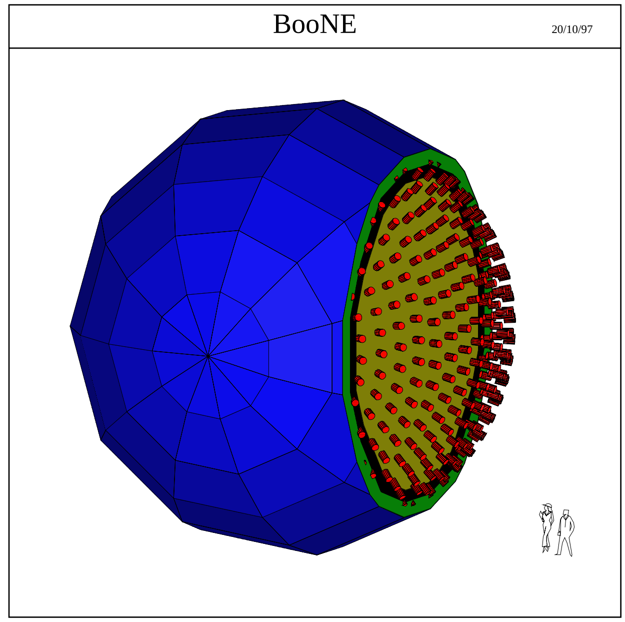

Figure 1: GEANT-generated schematic of the proposed detector.

Figure 2: Southwest region of the Fermilab site. The BooNE neutrino beam originates at the Main Injector and points almost due north. The Target Hall is located north of the Main Injector cooling ponds. The detector is located at a distance of 500 meters from the neutrino source.

2 BooNE

In Fig. 3 we show the portion of parameter space covered by the LSND effect. Most of this region has been excluded by other experiments, but there remains a region at Δm^2 between 0.1 and 1 eV^2 and small $\sin^2(2\theta)$ that is not covered by other experiments. The BooNE experiment, as seen in the figure, will completely cover this region.

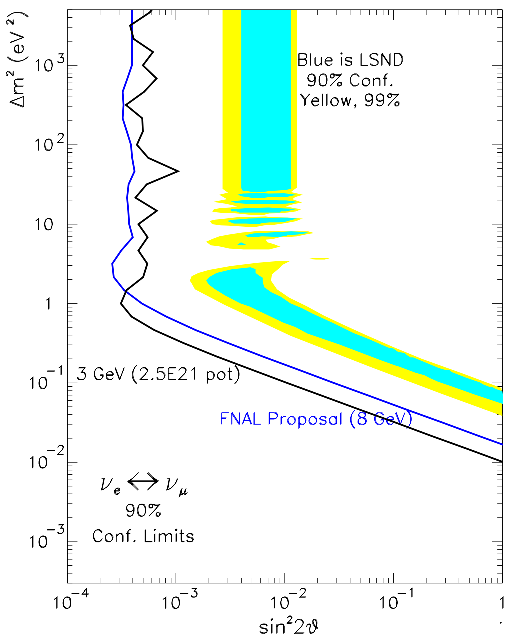

Figure 3: The region of parameter space covered by LSND, BooNE and a potential experiment carried out with a three GeV proton source.

3 The Horn Focusing System

The BooNE collaboration has not chosen a horn configuration for its experiment. However, to develop a baseline for flux comparisons, the BNL horn system is used to calculate neutrino fluxes and backgrounds. The horns [3], shown schematically in Fig. 4 would have a 250 KAmp current pulse. Other horn configurations are being studied to determine which would be best for BooNE, which has an added constraint that it must pulse at a 15 Hz rate.

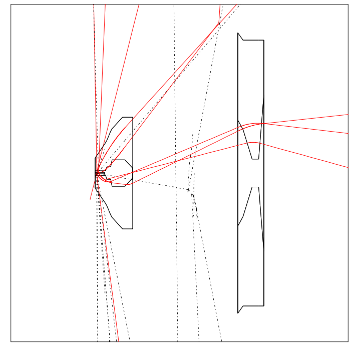

Figure 4: The magnetic horn system is shown schematically. The horns themselves are cylindrically symmetric, with the proton target enclosed in the entrance of the first horn. Representative rays are shown originating at the target.

4 Comparison with Other Potential Sources

In Fig. 3 we also show the potential for covering the LSND region with a neutrino beam generated by a three GeV proton source [4]. In this calculation we've also assumed the BNL horns, a fifty meter decay space, and a 500 meter distance between the detector and target. A 12 meter detector diameter was also assumed. The portion of parameter space that can be covered by the configuration is somewhat better than that covered by BooNE, although a high integrated flux of (2.5×10^{21}) protons on target is required. This is a factor of five greater than that assumed in the BooNE proposal.

The same calculation can be made for other sources. In Fig 5 we show a comparison with proton energies ranging from 3 to 15 GeV. The comparison is very favorable. In each case we've assumed (5.0×10^{20}) protons on target, except for the three GeV case which, as mentioned in the previous paragraph, requires a factor of five greater integrated proton intensity.

This favorable comparison indicates that the energy of the proton source is not a determining factor in siting a short baseline experiment. The region of parameter space that is covered by the experiment is apparently determined by the geographic parameters of the experiment, that is the decay length and distance to the de-

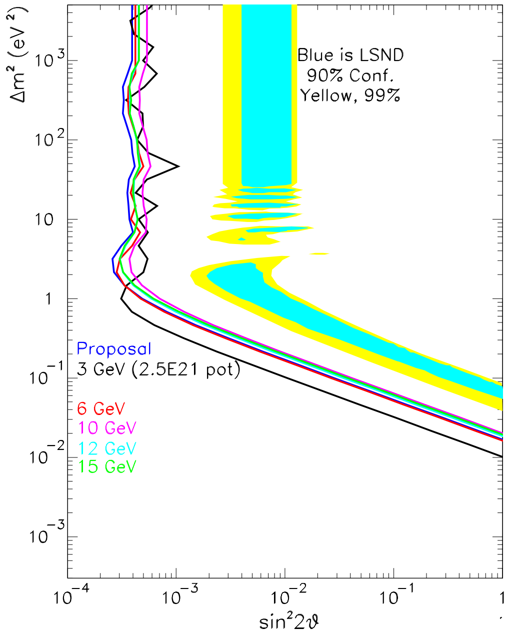

Figure 5: Variation in the region covered by potential short baseline experiments carried out with a variety of proton energy sources.

tector. We can understand this if we realized that the peak of the neutrino spectrum changes slowly as we vary the energy of the protons on target.

5 Flux Comparisons and ν_e Backgrounds

We can be more quantitative and compare the integrated flux for each of the primary energy configurations we calculated. This can be seen in Fig. 6. The total ν_μ flux, decreases substantially as we reduce the primary energy. However, the main background of ν_e in the beam decreases even more rapidly. At a low energy source, we may require more protons on target, but the ν_e backgrounds are more favorable. In Fig. 6 we show the contribution to the ν_e flux from kaon and muon decays. At three GeV, we do not generate kaons, so that they do not contribute as a source of ν_e. Muons are a source of ν_e at all energies. At three GeV, for example, we generate very low energy muons, all of which will most likely decay, that is, at low energies, muons are more likely to contribute to the ν_e background flux. However, when we add the ν_e background from K and μ decay, the overall effect is that this background is reduced as we reduce the proton energy on target.

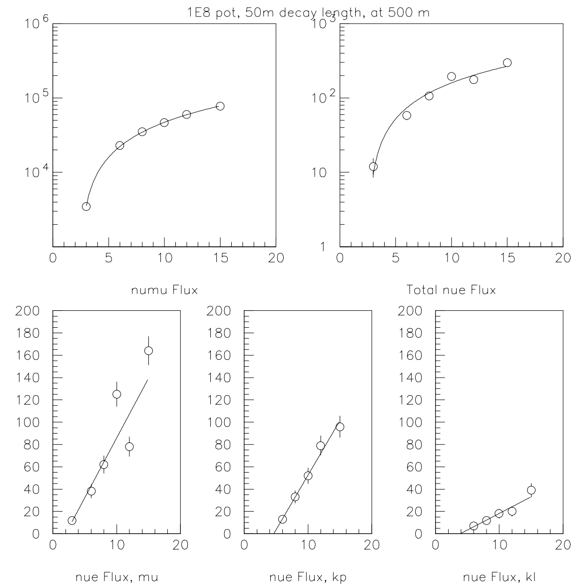

Figure 6: Comparison of the relative flux of ν_μ and ν_e as a function of the energy of the proton beam incident on the target. The BooNE focusing system, decay length, and distance to the detector are assumed in this Monte Carlo calculation.

6 Future Prospects with a Muon Storage Ring

Recently, there has been interest in other more novel approaches to generating neutrino beams for short baseline experiments [6]. Along with work toward developing the concepts associated with a muon collider, one can speculate on the advantages of using a muon storage ring as a neutrino source. The ring would be somewhat unusual, in that it would possess two long straight sections, basically acting as the decay pipe for the muons [5]. Such a source would have a distinct advantage, since the muon flux in the ring could be measured very accurately. The neutrino flux available from such a ring would be quite high as well. An oscillation experiment using such a source would probably look for $\nu_e \to \nu_\mu$ oscillations.

A ten GeV muon collider using superconducting magnets will provide 1.5 GeV in the same ring circumference with conventional magnets [5]. The size of the storage ring can be seen in Figure 7. The facility would fit nicely within the footprint of the Pbar Source at Fermilab.

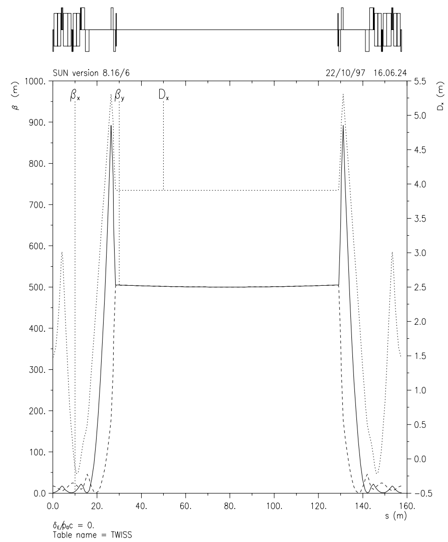

Figure 7: Half ring configuration for a muon storage ring. Ring energy is 10 GeV if superconducting magnets are used, and about 1.5 GeV if conventional magnets are used.

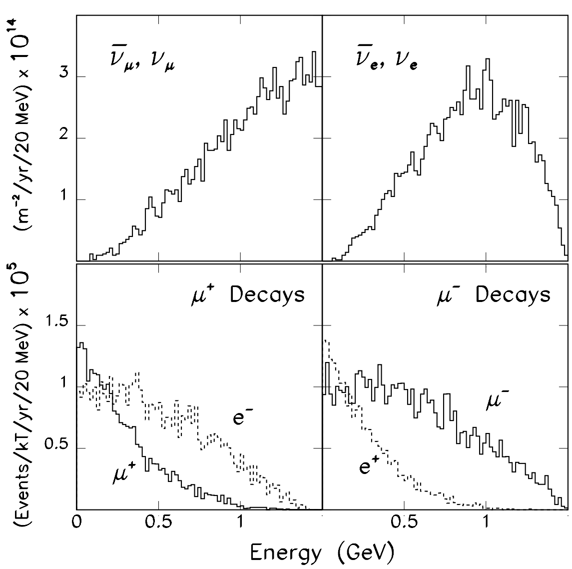

Figure 8: Expected neutrino flux and event rates from a 1.5 GeV muon storage ring. The half-ring configuration is given in Figure 7.

Operating at 1.5 GeV, the ring would provide a neutrino beam peaked at less than 1 GeV, ideal for tests in the LSND region.

The neutrino flux and event distributions from decays from muons in a storage ring of μ^+ is given in Figure 8 [6]. From the figure it is clear that substantial neutrino flux could be generated at such a facility. Also important to note is that this beam provides an opportunity for greater control of systematics than a horn generated beam.

Conclusion

Many options exist for short baseline neutrino experiments, some of which were covered in this presentation. In general, the development of a new facility such as JHF should keep in mind the possibilities for neutrino physics at a low-energy high-flux source.

Acknowledgments

This work was performed at the Fermi National Accelerator Laboratory, which is operated by the Universities Research Association, under contract DE-AC02-76CH03000 with the U.S. Department of Energy.

References

1. E. Church *et al.*, Proposal P898, submitted to Fermilab on December 7, 1997.
2. C. Athanassopoulos *et. al.* , Phys. Rev. Lett. **75**, 2650 (1995); C. Athanassopoulos *et. al.* , Phys. Rev. Lett. **77**, 3082 (1996); C. Athanassopoulos *et. al.* , Phys. Rev. C. **54**, 2685 (1996).
3. L. A. Ahrens *et. al.* , Phys. Rev. D **34**, 75 (1986).
4. These calculations were carried out by Janet Conrad.
5. The half ring design was provided by Carol Johnstone.
6. Steve Geer, submitted to PRD (Fermilab-pub-97/389).